(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 January 2002 (10.01.2002)

PCT

(10) International Publication Number
WO 02/02949 A1

(51) International Patent Classification[7]: F04C 18/16, 18/08

(21) International Application Number: PCT/US00/34871

(22) International Filing Date: 21 December 2000 (21.12.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/607,764 30 June 2000 (30.06.2000) US

(71) Applicant: CARRIER CORPORATION [US/US]; Carrier Parkway, P.O. Box 4800, Syracuse, New York 13221 (US).

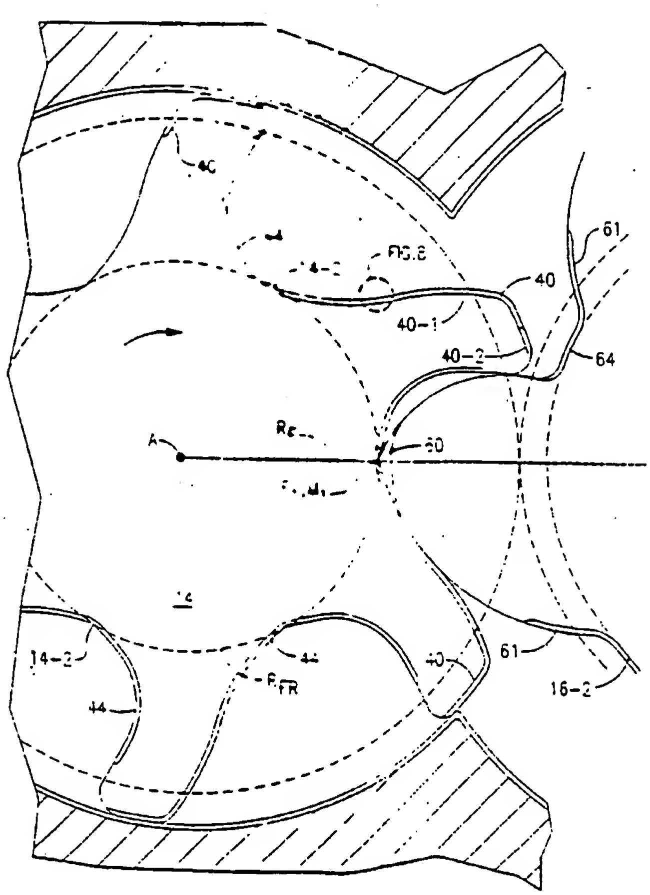
(72) Inventors: **BUSH, James, W.**; 11 Academy Street, Skaneateles, NY 13152 (US). **COOPER, Clark, V.**; 27 Cortland Lane, Glastonbury, CT 06033-3305 (US). **DROST, Ronald, T.**; 278 Prospect Hill Road, Colchester, CT 06415 (US). **DU, Hong**; Apartment 1205, 3 Village Way, Weathersfield, CT 06109 (US). **EATON, Harry, E.**; 391 Perrin Road, Woodstock, CT 06281 (US). **KHALIFA, Hussein, E.**; 8381 Turnberry Drive, Manlius, NY 13104 (US). **KUMAR, Keshava, B.**; 161 Natsisky Farm Road, South Windsor, CT 06074 (US). **LIN, Reng, Rong**; 4890 Bentbrook Drive, Manlius, NY 13104 (US). **MC CLUSKEY, Philip, H.**; 2025 West Murphy Drive, Dunlap, IL 61525 (US). **DE BLOIS, Raymond** (deceased).

(74) Agent: **HABELT, William, W.**; Carrier Corporation, Intellectual Property Dept., Carrier Parkway, P.O. Box 4800, Syracuse, NY 13221 (US).

(81) Designated States *(national)*: AU, BR, CN, IN, JP, KR.

[Continued on next page]

(54) Title: SCREW MACHINE



(57) Abstract: A screw machine (10) has a rotor housing (12) defining overlapping bores (12-1,12-2). Female rotor (14) is located in bore (12-1) and male rotor (16) is located in bore (12-2). A wear resistant coating is deposited on the tips (14-1, 16-1) of the rotors. A conformable coating is deposited on the valleys (14-2, 16-2) of the rotors. A conformable coating is deposited on the surface of the bores coacting with the rotors.

WO 02/02949 A1

(84) **Designated States** *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SCREW MACHINE

Background of the Invention

In a conventional screw machine, a male rotor and a female rotor, disposed in respective parallel overlapping bores defined within a rotor housing, coact to trap and compress volumes of gas. While two rotors are the most common design, three, or more, rotors may coact in pairs. The male and female rotors differ in their lobe profiles and in the number of lobes and flutes. For example, the female rotor may have six lobes separated by six flutes, the while conjugate male rotor may have five lobes separated by five flutes. Accordingly, each possible combination of lobe and flute coaction between the rotors occurs on a cyclic basis. The coaction between the conjugate pairs of rotors is a combination of sliding and rolling contact which can produce different rates of wear. In addition to coacting in pairs, the rotors coact as well with the housing. Because all combinations of rotor contact takes place between conjugate pairs, the sealing/leakage between the various combinations may be different due to manufacturing tolerances and wear patterns. This can be the case even though manufacturing tolerances are held very tight with the attendant manufacturing costs and adequate lubrication or other liquid injection is provided for sealing.

The profile design of conjugate pairs of screw rotors must be provided with a clearance in most sections. The need to provide a clearance is the result of a number of factors including: thermal growth of the rotors as a result of gas being heated in the compression process; deflection of the rotors due to pressure loading resulting from the compression process; tolerances in the support bearing structure and machining tolerances on the rotors which may sometimes tend to locate the rotors too close to one another which can lead to interference; and machining tolerances on the rotor profiles themselves which can also lead to interference. Superimposed upon these factors is the existence of pressure and thermal gradients as the pressure and temperature increase in going from suction to discharge.

The pressure gradient is normally in one direction during operation such that fluid pressure tends to force the rotors towards the suction side. The rotors are conventionally mounted in bearings at each end so as to provide both radial and axial restraint. The end clearance of the rotors at the discharge side is critical to sealing and the fluid pressure tends to force open the clearance.

There are certain sections of the rotor, such as the contact band, where zero clearance is maintained between the rotors. The segment of the rotor defining the contact band is the region where the required torque is transmitted between the rotors. The load between the rotors is different for a male rotor drive and for a female rotor drive. In a male drive the loading between the rotors may be equivalent to about 10% of the total compressor torque, whereas in the case of female rotor drive the loading between the rotors may be equivalent to about 90% of the total compressor torque. These segments are conventionally positioned near the pitch circles of the rotors which is the location of equal rotational speed on the rotors resulting in rolling contact and thereby in reduced or no sliding contact and thus less wear.

A substantial amount of end-running clearance must be maintained at the discharge end of screw compressors in order to prevent failure from rotor seizure. Seizure may be caused by the thermal expansion of the rotor or by the intermittent contacts between the rotors and the end casing due to pressure pulsations in the compression process.

<u>Summary of the Invention</u>

It is an object of this invention to reduce leakage in a screw machine.

It is another object of this invention to relax machining tolerances without increasing leakage.

It is a further object of this invention to reduce oil sealing requirements in screw machines.

It is an additional object of this invention to minimize the power loss due to friction and to prevent wear. These objects, and others as will become apparent hereinafter, are accomplished by the present invention

In accordance with the present invention, a coating is applied to one or more portions of the screw rotors and/or the inner bore surfaces of the housing.

In one aspect of the present invention, a low friction, wear resistant material may be deposited on the rotor tip where the rotors can have nominal contact with the housing as well as normal contact with each other. The rotors coact with each other, in pairs, as well as with the housing. While tight machining tolerances reduce the leakage due to these coactions between the rotors themselves and also with the housing, other things can be done in conjunction with the tight tolerances or in lieu of tight tolerances. Examples of suitable low friction, wear resistant coatings include multi-layer diamond-like-carbon (DLC) coating, titanium nitride and other single material, single layer nitride coatings, as well as carbide and ceramic coatings having both high wear resistance and a low coefficient of friction.

In another aspect of the present invention, conformable coatings may be located on the inner bore surfaces of the housing and/or in the rotor valleys. Examples of suitable conformable coatings include iron phosphate coating, magnesium phosphate coating, nickel polymer amalgams and other materials that yield elastically when a force is applied. Placement of conformable coatings on the inner bore surfaces of the housing and/or in the rotor valleys can reduce leakage and oil sealing requirements while relaxing manufacturing tolerances.

A surface coated or otherwise equivalently treated with such a low friction, wear resistant material is more forgiving to sliding contact than is an untreated surface. There also exists a synergistic effect associated with such a treatment in that the coated surface has a greater tolerance to sliding contact. In accordance with a further aspect of the present invention, this allows the contact band to be moved further away

from the pitch circle, thus further reducing the contact force and reducing the overall wear potential over even the treated rotor with a relocated contact band. Locating the contact band near the pitch circles of the rotors is the conventional practice, as noted, and represents the desire to have nearly pure rolling contact.

The location of the contact band is a design feature and can be removed from the pitch circle or otherwise located where you wish. By moving the contact band away from the pitch circle the loading between the rotors can be reduced and this is particularly important for a female rotor drive. As contact starts to move away from the pitch circle there is more sliding contact rather than pure rolling contact. The blow hole area, which refers to the leakage area defined by the meshing rotor tips and the edge of the cusp between adjacent bores of a screw machine, can only be reduced to zero if the respective pitch circles correspond to the root circle of the male rotor and the tip circle of the female rotor. This necessarily requires the contact band to be located away from the pitch circle in response to trade-offs between the transmission angle, contact pressure, machineability of the root radius of the male rotor, and the amount of sliding that will take place.

The penalty for maintaining this large end-running clearance is to increase the leakage from the high pressure zone into the low pressure zone. In accordance with a further aspect of the present invention, by applying a wear resistant coating having a low coefficient of friction at the end face of the rotors or at the surface of the end casing or by inserting a coated piece between the rotor ends and the end casing, the end-running clearance can be reduced at least by 50%. The compressor performance is improved due to the reduced leakage at the discharge end.

<u>Brief Description of the Drawings</u>

For a fuller understanding of the present invention, reference should now be made to the following detailed description of various embodiments thereof taken in conjunction with the accompanying drawings wherein:

Figure 1 is a transverse section through a screw machine;

Figure 2 is a partially sectioned view of the screw machine of Figure 1;

Figure 3 is an enlarged view of a portion of the discharge end of the screw machine of Figure 1;

Figure 4 is an enlarged portion of Figure 1 with the various coatings of the present invention illustrated;

Figure 5 is a partially sectioned view showing a DLC coating on the rotor ends;

Figure 6 is a partially sectioned view showing a DLC coating on the on the discharge casing; and

Figure 7 is a partially sectioned view showing a DLC coated disc;

Figure 8 is an enlarged view of a DLC coating; and

Figure 9 is a perspective view of an axial section of the rotor pair of Figure 1.

Description of the Preferred Embodiments

In Figure 1, there is depicted a screw machine 10, such as a screw compressor, having a rotor housing or casing 12 with overlapping bores 12-1 and 12-2 located therein. Female rotor 14 having a pitch circle, P_F, is located in bore 12-1. Male rotor 16 having a pitch circle, P_M, is located in bore 12-2. The parallel axes indicated by points A and B are perpendicular to the plane of Figure 1 and separated by a distance equal to the sum of the radius, R_F, of the pitch circle, P_F, of female rotor 14 and the pitch radius, R_M, of the pitch circle, P_M, of male rotor 16. The axis indicated by point A is the axis of rotation of female rotor 14 and generally of the center of bore 12-1 whose diameter generally corresponds to the diameter of the tip circle, T_F, of female rotor 14.

Similarly, the axis indicated by point B is the axis of rotation of male rotor 16 and generally of the center of bore 12-2 whose diameter generally corresponds to the diameter of the tip circle, T_M, of male rotor 16. Typically, the rotor and the bore centerlines are offset by a very small amount to compensate for clearance and deflection. Neglecting operating clearances, the extension of the bore 12-1 through the overlapping portion with bore 12-2 will intersect line A-B at the tangent point with the root circle, R_{MR}, of male rotor 16. Similarly, the extension of the bore 12-2 through the overlapping portion with bore 12-1 will intersect line A-B at the tangent point with the root circle, R_{FR}, of female rotor 14 and this common point is labeled F_1 relative to female rotor 14 and M_1 relative to male rotor 16.

In the illustrated embodiments, female rotor 14 has six lands or tips, 14-1, separated by six grooves or flutes, 14-2, while male rotor 16 has five lands or tips, 16-1, separated by five grooves or flutes 16-2. Accordingly, the rotational speed of rotor 16 will be 6/5 or 120% of that of rotor 14. Either the female rotor 14 or the male rotor 16 may be connected to a prime mover (not illustrated) and serve as the driving rotor. Other combinations of the number of female and male lands and grooves may also be used.

Referring now to Figures 2 and 3, rotor 14 has a shaft portion 14-3 with a shoulder 14-4 formed between shaft portion 14-3 and rotor 14. Shaft portion 14-3 of rotor 14 is supported in outlet or discharge casing 13 by one, or more, bearing(s) 30. Similarly, rotor 16 has a shaft portion 16-3 with a shoulder 16-4 formed between shaft portion 16-3 and rotor 16. Shaft portion 16-3 of rotor 16 is supported in outlet casing 13 by one, or more bearing(s) 31. Suction side shaft portions 14-5 and 16-5 of rotors 14 and 16, respectively, are supportingly received in rotor housing 12 by roller bearings 32 and 33, respectively.

In operation, as a refrigerant compressor, assuming male rotor 16 to be the driving rotor, rotor 16 rotates engaging rotor 14 and causing its rotation. The coaction of rotating rotors 16 and 14, disposed within the respective bores 12-1 and 12-2, draws refrigerant gas via suction inlet 18 into the grooves of rotors 16 and 14 which engage

to trap and compress volumes of gas and deliver the hot compressed gas to discharge port 19. The trapped gas acting on rotors 14 and 16, which are movable, tends to separate discharge ends 14-4 and 16-4 from outlet casing surface 13-1 to create/increase the leak passage. Movement of rotors 14 and 16 away from outlet casing surface 13-1 results in movement of rotors 14 and 16 towards or into engagement with surface 12-3 of rotor casing 12 by shoulders 14-6 and 16-6, respectively. In addition to the leak path between rotor shoulders 14-4 and 16-4 and outlet casing surface 13-1, leakage can occur across the line contact between rotors 14 and 16 as well as between the tips of lands 14-1 and 16-1, respectively, and bores 12-1 and 12-2, respectively. The leakage across the lands/line contact can be reduced by the use of oil for sealing but the oil generates a viscous drag loss between the moving parts and must be removed from the discharge gas.

As noted hereinbefore, the contact band is defined by zero clearance rather than by location. Figure 4 shows an enlarged portion of Figure 1 in order to illustrate the relocation of the contact band in accordance with one aspect of the present invention. The contact band would be located inside of the pitch circle, P_F, of female rotor 14 which is in the region of the female tip 14-1 and outside of the pitch circle, P_M, of male rotor 16 which is in the region of the male root 16-2.

For an oil-free compressor, the rotor tips must be brought as close as possible to the rotor housing bores 12-1 and 12-2 in order to reduce the leakage since oil cannot be used for sealing. The wear and power loss due to the friction between the rotor tips and the housing will be excessive if contact occurs between the rotors and housing. Even where the rotors are lubricated, there can be leakage across the oil seal and the oil must be removed from the refrigerant to minimize its circulation through the refrigeration system with its deterioration of the heat transfer efficiency as well as to maintain the necessary oil for lubrication in the compressor.

In accordance with one aspect of the present invention, a low friction, wear resistant coating is deposited on the tips or lands 14-1 and 16-1 of the rotors 14 and 16, respectively. One suitable low friction, wear resistant coating is a low friction

diamond-like-carbon (DLC) coating of the type used locally on the tip surface of the vane in a rotary compressor as disclosed in commonly assigned U.S. Patent No. 5,672,054. Such a the DLC coating serves to overcome lubrication difficulties associated with the use of new oil and refrigerant combinations. The DLC coating is both lubricous and also wear resistant in that, as discussed in detail in U.S. Patent 5,672,054, the entire disclosure of which is hereby incorporated by reference, it is made up of alternating layers of a hard material, such as tungsten carbide, and amorphous carbon.

Examples of other suitable low friction, wear resistant coatings include titanium nitride and other single material, single layer nitride coatings, as well as carbide and ceramic coatings having both high wear resistance and a low coefficient of friction. The presence of a low friction, wear resistant coating on the tips or in the valleys of lands of the respective rotors provides several advantages. First, oil free or reduced oil operation relative to the rotors is possible without excessive wear or friction. Second, machining tolerances can be relaxed because some contact with the rotor bores can be tolerated. Third, the need for oil sealing between the rotors and the rotor bores can be reduced or eliminated because of the possibility of running with less clearance between the rotor tips or lands 14-1 and 16-1 and rotor bores 12-1 and 12-2, respectively.

Because the contact band on female rotor 14 is located near the tip, a single DLC coating can be used to cover both areas of interest on the female rotor due to their narrow spacing, or overlap, depending upon the rotor profiles. The single DLC coating 40 on the female rotor is preferred for ease of manufacture as illustrated on Figure 4. The portion 40-1 of coating 40 corresponds to the contact band and the portion 40-2 corresponds to the portion of tip or land 14-2 that comes closest to bore 12-1. The corresponding DLC coatings on male rotor 16 are more widely separated with the coating 60 deposited on the rotor tips and the coating 60 deposited near the root portion corresponding to the contact band.

Like the rotor tips, the rotor ends are run with a clearance that constitutes a leak path. In accordance with a further aspect of the present invention, a DLC coating may be applied at the discharge end faces of the rotors, at the facing surfaces of the discharge casing 13 or on a coated insert disposed between the rotors and the discharge casing 13, whereby the running clearance, and thereby the leakage path, is reduced. Referring now to Figure 5, a DLC coating is applied to the discharge end of the rotors 14 and 16. Specifically, DLC coating 42 is applied to the discharge end of female rotor 14 and DLC coating 62 is applied to the discharge end of male rotor 16. Because the DLC coatings 42 and 62 can accommodate some contact with outlet casing surface 13-1, a reduced end running clearance can be employed with reduced leakage. Referring now to Figure 6, the DLC coating 82 is applied to the casing surface 13-1 rather than to the ends of the rotors 14 and 16, as in the Figure 5 embodiment. In the Figure 7 embodiment, a separate member 90 is located between the ends of rotors 14 and 16 and casing surface 13-1. Because the member 90 conforms to the cross section of bores 12-1 and 12-2, it is not capable of rotation and the relative movement will be between member 90 and the discharge ends of rotors 14 and 16. Accordingly, only the surface of member 90 facing rotors 14 and 16 needs to be provided with a DLC coating 92. In the embodiments of Figures 5-7 a DLC coating is located between the ends of rotors 14 and 16 and surface 13-1 such that its lubricity will protect the rotors and casing from wear during an occasional contact thereby permitting the closing of the end running clearance and narrowing the leakage path.

Referring now to Figure 8, a greatly exaggerated cross section typical of coatings 40, 42, 60, 61, 82 and 92 is illustrated although it is labeled 40. DLC coating 40 is made up of hard bilayers 40' and lubricious bilayers 40". The range of bilayer thickness is 1 to 20nm, with the preferred range being between 5 and 10nm.

In accordance with a further aspect of the present invention, a conformable coating, which may be abradable or extrudable into shape, may be applied to the rotors 14 and 16 and/or to the bores 12-1 and 12-2. While the entire rotors and bores may be coated, a localized coating in the rotor flutes or valleys 14-2 and 16-2, respectively, as

illustrated in Figure 9, provides essentially all of the benefits relative to the coaction between the rotors. Although the contact band is a no clearance area and requires precise machining, the tolerances can be relaxed relative to the coaction between the remainder of the rotor lobe profiles. Additionally, the conformable coating of the bores 12-1 and 12-2 accommodates the flexure of the rotors 14 and 16 during actual operation to maintain the sealing function. Referring to Figures 4 and 9, the female rotor valleys may be provided with conformable coating 44 and the male rotor valley may be provided with conformable coating 64. Additionally, bores 12-1 and 12-2 may be provided with conformable coating 84.

Various plastically conformable coatings may be used including, for example, iron phosphate, magnesium phosphate, nickel polymer amalgams, nickel zinc alloys, aluminum silicon alloys with polyester, and aluminum silicon alloys with polymethylmetacrylate (PMMA). Also, convention coatings methods, including for example thermal spraying, physical vapor deposition (PVD), chemical vapor deposition (CVD), or any suitable aqueous deposition, may be used to treat the surfaces of the screw machine of the present invention.

Although the present invention has been specifically illustrated and described in terms of a twin rotor screw machine, it is applicable to screw machines employing three, or more rotors. It is therefore intended that the present invention is to be limited only by the scope of the appended claims.

CLAIMS

What is Claimed is:

1. A screw machine comprising a rotor housing having a pair of parallel, overlapping bores; a conjugate pair of intermeshing rotors located in said bores, each of said rotors having helical lobes having radially outward tip portions and intervening radially inward root portions; characterized by at least either said bores or said lobes having a conformable coating thereon.

2. The screw machine of claim 1 wherein said tip portions of said lobes of said rotors have a wear resistant coating thereon.

3. The screw machine of claim 2 wherein said conformable coating is located on said root portions of said lobes of said rotors.

4. The screw machine of claim 2 wherein the wear resistant coating on the tip portions of said lobes comprises a diamond-like-carbon coating made up of a series of alternating hard and lubricious layers.

5. the screw machine of claim 4 wherein said conformable coating is located on said root portions of said lobes of said rotors.

6. The screw machine of claim 5 wherein said bores are lined with a conformable coating.

7. The screw machine of claim 1 wherein said conformable coating is located on said root portions of said lobes of said rotors.

8. The screw machine of claim 7 wherein said bores re lined with a conformable coating.

9. The screw machine of claim 1 wherein said bores are lined with a conformable coating.

10. A screw machine comprising a rotor housing having a pair of parallel, overlapping bores; a conjugate pair of intermeshing rotors located in said bores, each of said rotors having helical lobes and intervening flutes; an outlet casing disposed at a discharge end of said rotor housing, each of said rotors having a discharge end facing said outlet casing; characterized by a wear resistant coating disposed between said discharge ends of said rotors and said outlet casing.

11. The screw machine of claim 10 wherein said wear resistant coating comprises a wear resistant coating on said discharge ends of said rotors.

12. The screw machine of claim 11 wherein said wear resistant coating comprises a diamond-like-carbon coating made up of a series of alternating hard and lubricious layers.

13. The screw machine of claim 10 wherein said wear resistant coating comprises wear resistant coating on said outlet casing.

14. The screw machine of claim 13 wherein said wear resistant coating comprises a diamond-like-carbon coating made up of series of alternating hard and lubricious layers.

15. The screw machine of claim 10 further characterized by a member located intermediate said discharge ends of said rotors and said outlet casing, said member having a surface facing said discharge ends of said rotors, said wear resistant coating comprising a wear resistant coating on said surface of said member.

16. The screw machine of claim 15 wherein said wear resistant coating comprises a diamond-like-carbon coating made up of a series of alternating hard and lubricious layers.

17. A screw machine comprising a rotor housing having a pair of parallel, overlapping bores; a conjugate pair of intermeshing rotors located in said bores, each of said rotors having helical lobes having radially outward tip portions and intervening flutes having radially inward root potions; characterized by a wear resistant coating disposed on the tip portions of said lobes.

18. The screw machine of claim 17 wherein said bores are lined with a conformable coating.

19. The screw machine of claim 18 wherein a conformable coating is located on said root portions of said lobes of said rotors.

20. The screw machine of claim 17 wherein said wear resistant coating comprises a diamond-like-carbon coating made up of a series of alternating hard and lubricious layers.

21. The screw machine of claim 20 wherein said bores are lined with a conformable coating.

22. The screw machine of claim 21 wherein a conformable coating is located on said root portions of said lobes of said rotors.

23. The screw machine of claim 17 wherein a conformable coating is located on said root portions of said lobes of said rotors.

24. A screw machine comprising a rotor housing having a pair of parallel, overlapping bores; a conjugate pair of intermeshing rotors located in said bores, each of said rotors having helical lobes and intervening flutes; said rotors having contact bands whereat torque is transmitted from one rotor to another rotor; characterized by a wear resistant coating disposed on the contact bands of said rotors.

25. The screw machine of claim 24 wherein the contact bands on said rotors re located away from the respective pitch circles of said rotors.

26. The screw machine of claim 24 wherein said wear resistant coating comprises a diamond-like-carbon coating made up of a series of alternating hard and lubricious layers.

27. The screw machine of claim 26 wherein the contact bands on said rotors are located away from the respective pitch circles of said rotors.

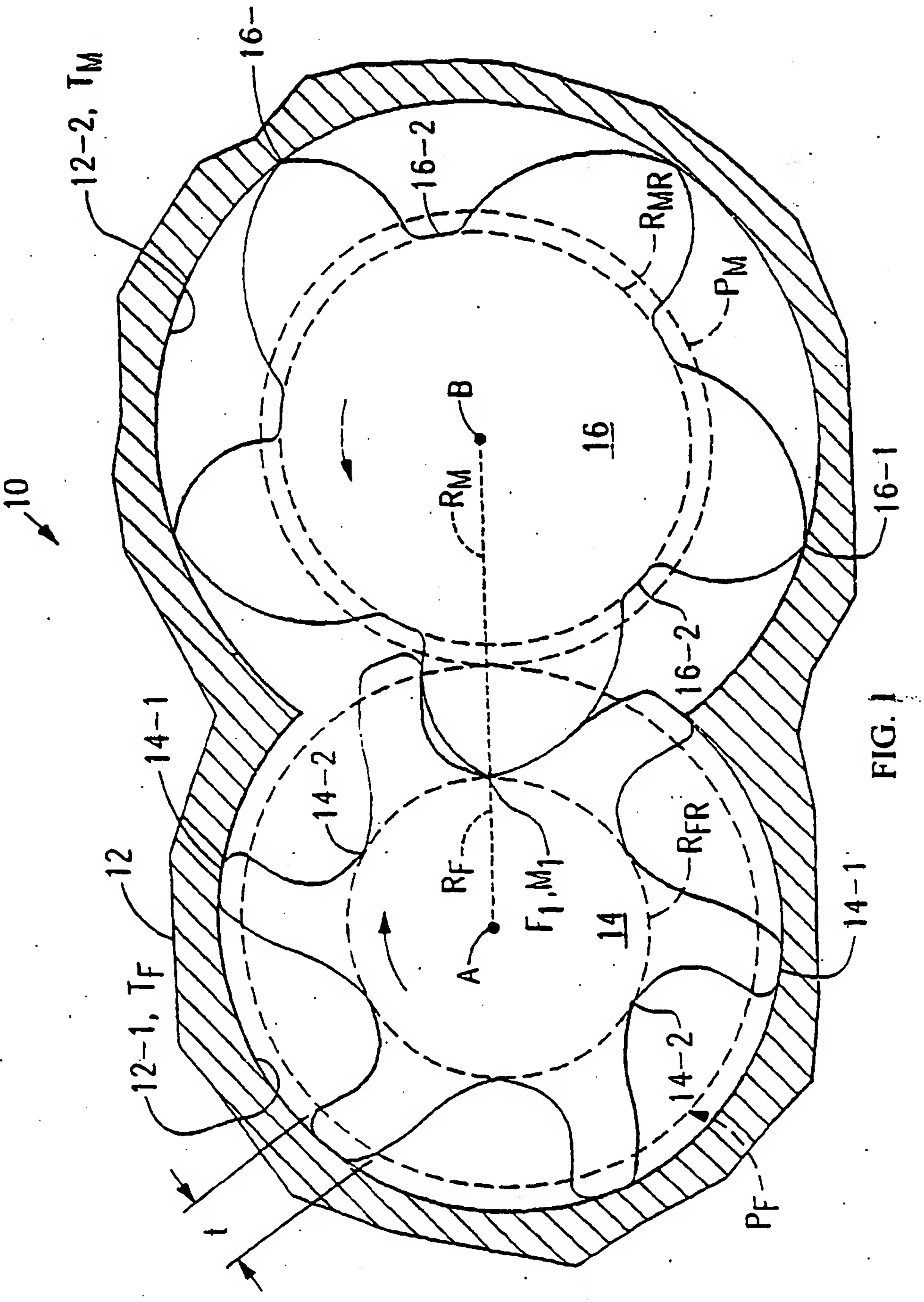
28. A screw machine comprising a rotor housing having a pair of parallel, overlapping bores; a conjugate pair of intermeshing rotors located in said bores, each of said rotors having helical lobes and intervening flutes; an outlet casing disposed at a discharge end of said rotor housing, each of said rotors having a

discharge end facing said outlet casing; characterized by a conformable coating disposed between said discharge ends of said rotors and said outlet casing.

29. The screw machine of claim 28 wherein said conformable coating comprises a coating on said discharge ends of said rotors.

30. The screw machine of claim 28 wherein said conformable coating comprises a coating on said outlet casing.

31. The screw machine of claim 28 further characterized by a member located intermediate said discharge ends of said rotors and said outlet casing, said member having a surface facing said discharge ends of said rotors, said conformable coating comprising a coating on said surface of said member



10
12
12-1, T_F
12-2, T_M
14
14-1
14-2
16
16-1
16-2
A
B
R_F
R_M
R_{FR}
R_{MR}
P_F
P_M
F_1, M_1
t

FIG. 1

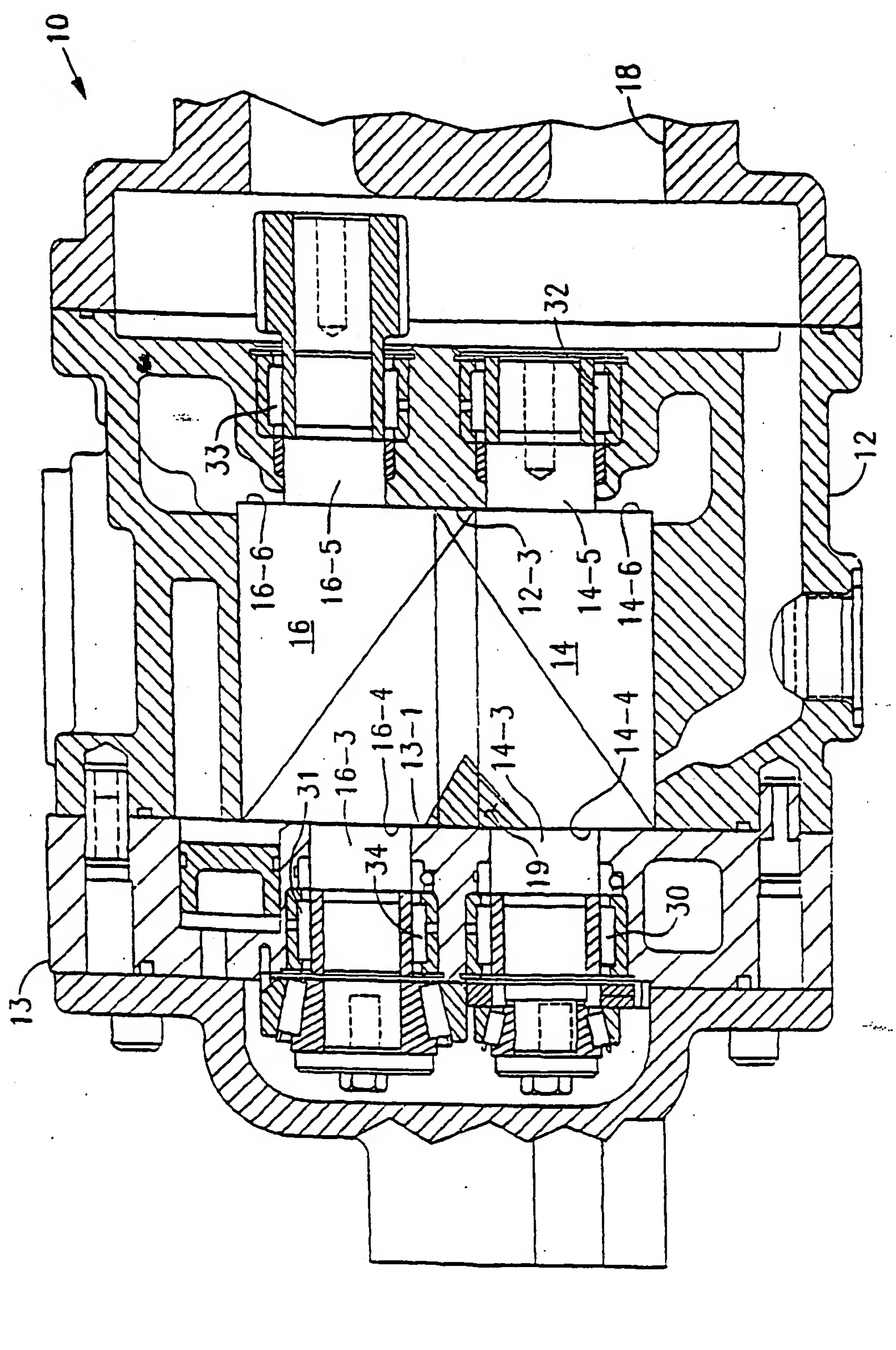

10
18
32
12
33
16-6
16-5
12-3
14-5
14-6
16
14
16-4
13-1
16-3
31
14-3
14-4
34
19
30
13

FIG. 2

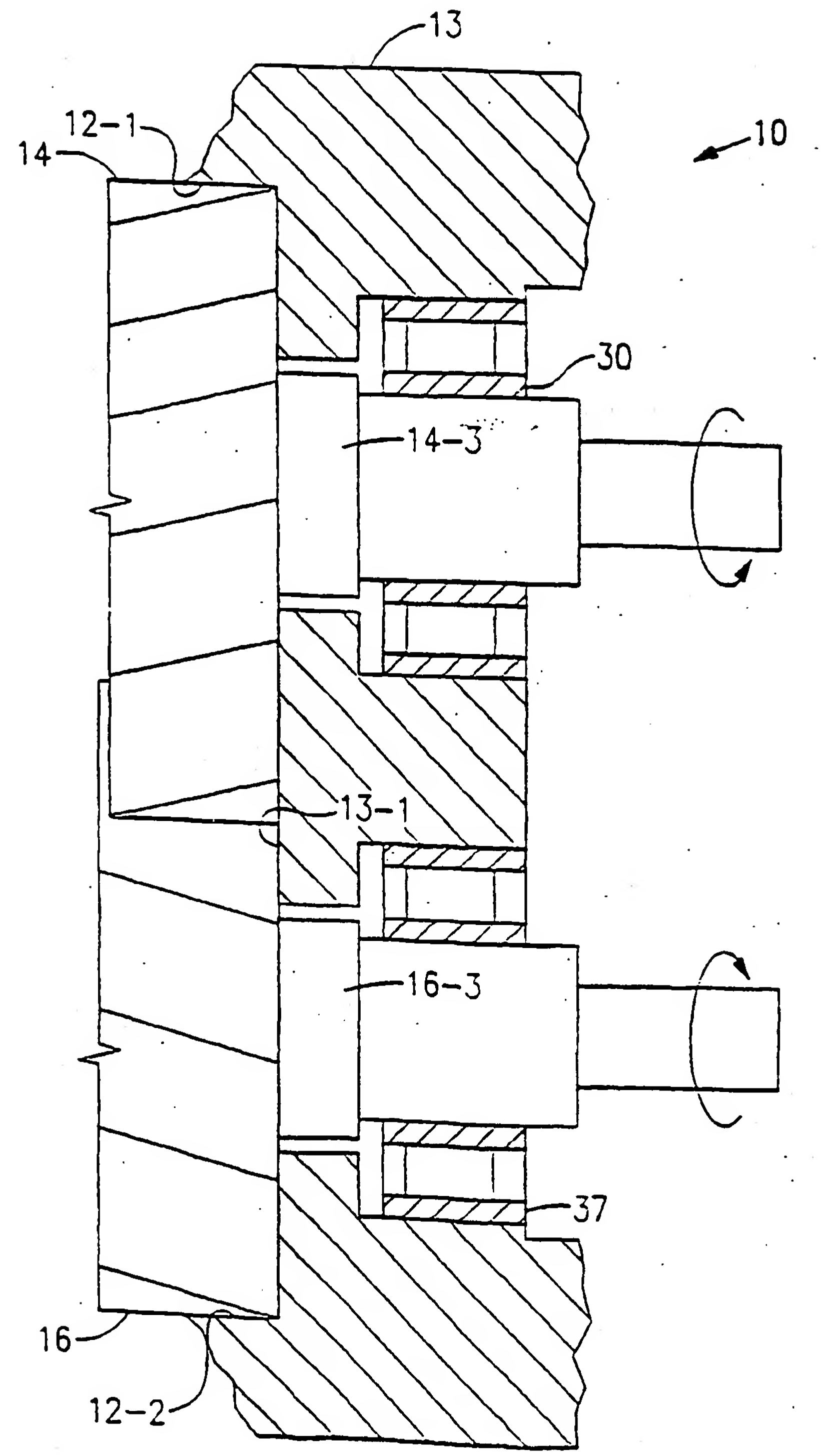


FIG. 3

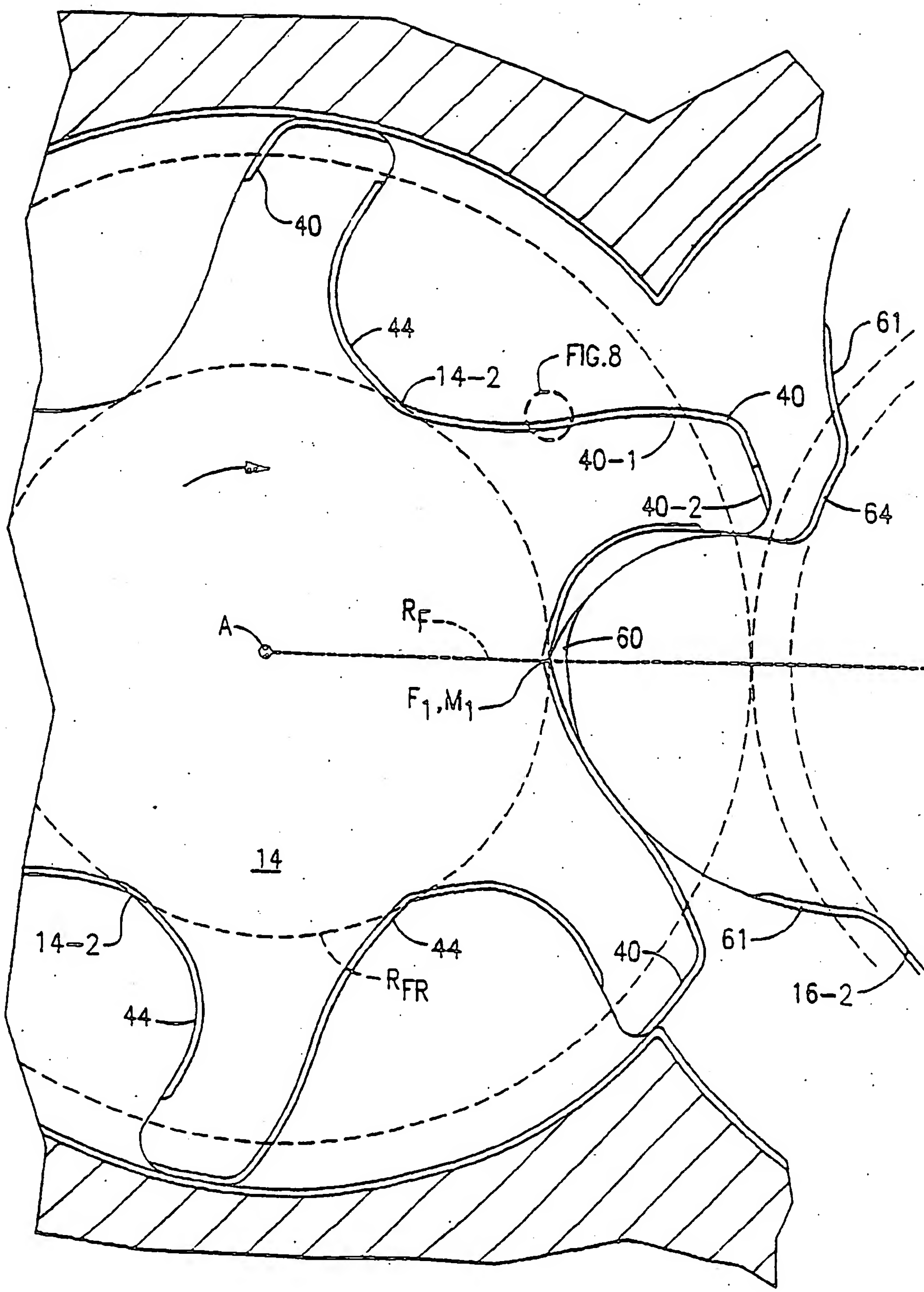

40
44
14-2
FIG.8
40
40-1
40-2
61
64
A
R_F
60
F_1,M_1
14
14-2
44
R_{FR}
44
40
61
16-2

FIG. 4

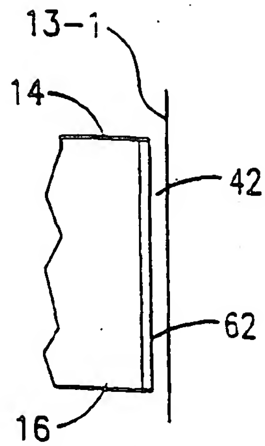


FIG. 5

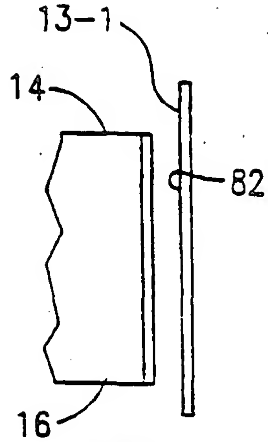


FIG. 6

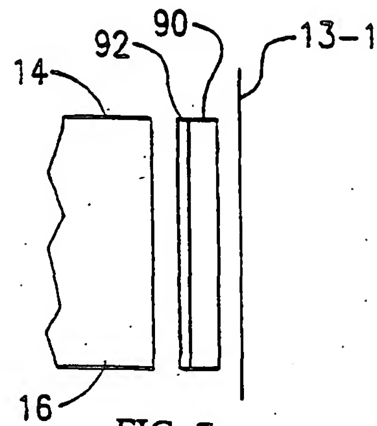


FIG. 7

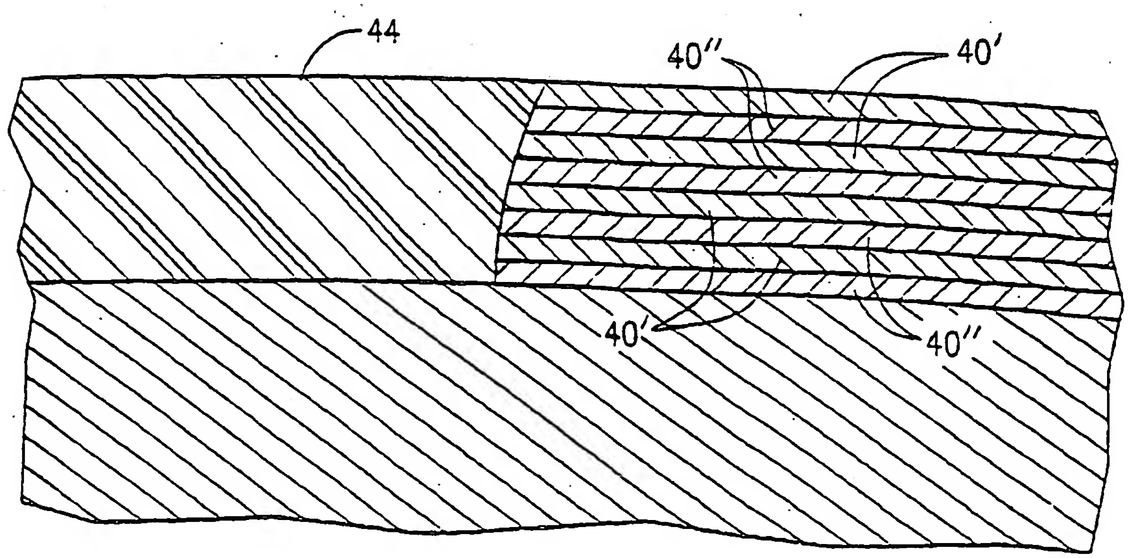


FIG. 8

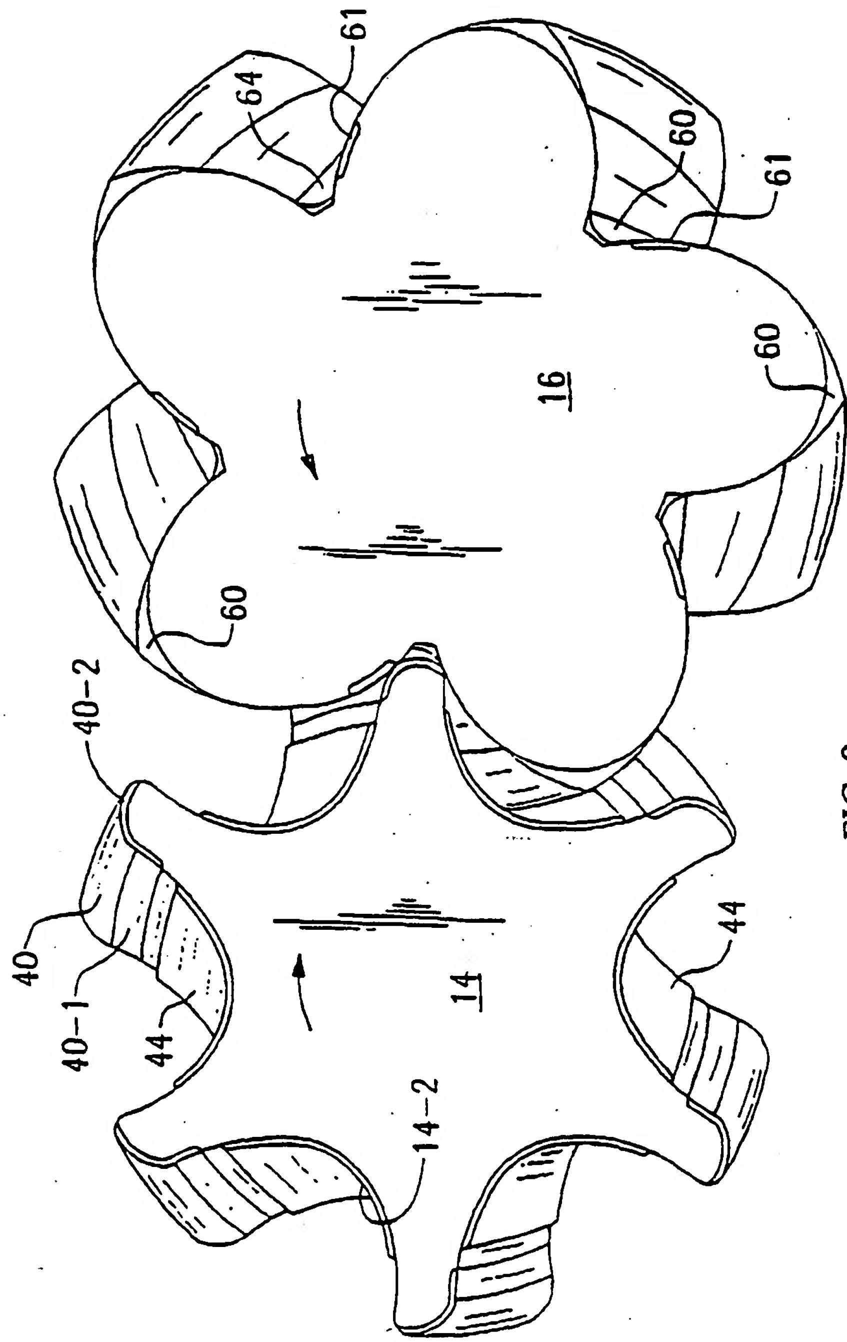


FIG. 9

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F04C18/16 F04C18/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F04C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 672 054 A (COOPER CLARK V ET AL) 30 September 1997 (1997-09-30) cited in the application claim 1 ---	1-31
Y	GB 2 121 112 A (BAMMERT KARL) 14 December 1983 (1983-12-14) the whole document ---	1-31
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 11, 29 November 1996 (1996-11-29) -& JP 08 177772 A (KYOCERA CORP), 12 July 1996 (1996-07-12) abstract; figure 2 ---	1-31

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2001	19. 03. 2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Dimitroulas, P

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 288 556 A (LEMELSON JEROME H) 22 February 1994 (1994-02-22) claims 1,2; figures 1-4	1-31
A	EP 0 378 009 A (ISHIKAWAJIMA HARIMA HEAVY IND) 18 July 1990 (1990-07-18)	
A	US 4 695 233 A (MIYOSHI KIYOTADA ET AL) 22 September 1987 (1987-09-22)	
A	US 5 364 250 A (AOKI MASAKAZU ET AL) 15 November 1994 (1994-11-15)	

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5672054	A	30-09-1997	BR	9607029	A	04-11-1997
			CN	1172521	A	04-02-1998
			EG	21022	A	30-09-2000
			EP	0808423	A	26-11-1997
			JP	2904589	B	14-06-1999
			JP	10505650	T	02-06-1998
			TW	384359	B	11-03-2000
			WO	9721033	A	12-06-1997
			US	5947710	A	07-09-1999
GB 2121112	A	14-12-1983	DE	3220516	A	01-12-1983
			BE	896887	A	16-09-1983
			FR	2527701	A	02-12-1983
			IT	1169432	B	27-05-1987
			JP	58214601	A	13-12-1983
JP 08177772	A	12-07-1996	NONE			
US 5288556	A	22-02-1994	US	4859493	A	22-08-1989
			US	4960643	A	02-10-1990
			US	5456406	A	10-10-1995
			US	4974498	A	04-12-1990
			US	5096352	A	17-03-1992
			US	5040501	A	20-08-1991
			US	5067826	A	26-11-1991
			US	5255929	A	26-10-1993
			US	5132587	A	21-07-1992
			US	5284394	A	08-02-1994
			US	6083570	A	04-07-2000
			US	5332348	A	26-07-1994
			US	5360227	A	01-11-1994
EP 0378009	A	18-07-1990	US	5060531	A	29-10-1991
US 4695233	A	22-09-1987	NONE			
US 5364250	A	15-11-1994	JP	6101670	A	12-04-1994

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Present claims 1-31 relate to an extremely large number of possible products. In fact, the claims contain so many options that a lack of clarity (and conciseness) within the meaning of Article 6 PCT arises to such an extent as to render a meaningful search of the claims impossible. Consequently, the search has been carried out for those parts of the application which do appear to be clear , namely the use of wear resistant coating and diamond-like-carbon coating. The term conformable coating is not clear.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.